TESTS OF AN EXPLOSIVE-DRIVEN COAXIAL GENERATOR*

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Abstract

The results of four tests on an explosive-driven sweeping-wave coaxial generator are reported. The first shot of the series used a capacitor bank to supply the initial current. The remaining three shots used an explosive-driven sweeping-wave helical generator to boost the initial current. On the final shot, a peak current of 50 MA was reached in a 12 nH load, corresponding to a peak energy of 15 MJ. The peak power was 1.5 TW and the final current-doubling time was 12.5 μs. In addition to conventional Rogowsky loops, Faraday rotation sensors were employed to measure the current. Arrays of microballoon optical-fiber pins were used to measure the shape of the armature under the action of the magnetic forces in the generator. The coaxial generator should be capable of achieving still higher output energies if higher input energies are provided.

Principle of Operation

The sweeping-wave coaxial generator was designed in response to requirements of the Los Alamos imploding foil program. A power source was needed that would deliver 20 MJ to a 10 nH inductive load with a final current-doubling time of 10 μs. System design considerations indicated that the output should be coaxial and the generator volume should be evacuated. The rationale behind these requirements has been presented elsewhere.[1,2]

The behavior of the sweeping-wave coaxial generator is depicted schematically in Fig. 1. Initially, a current through the generator and load produces magnetic flux in the generator volume. The armature is a hollow metal tube filled with explosive that is detonated at the input end of the device. The armature expands radially, first crowbarring the input and trapping the flux. As the detonation front moves toward the output end, the armature assumes the conical shape indicated in the figure. The flux in the generator volume and load is conserved approximately, since good conductors are used throughout. As the generator volume and inductance decrease, the current increases and the flux is swept into the load. The total energy delivery time of the device is set by the length of the generator and the detonation velocity. The current-doubling time is set by the time required for the generator inductance to decrease from the load inductance value to zero at the end of the run. The cone angle of the armature should match closely the angle of the stator at the output end.[2] If the armature angle is smaller than the stator angle, the generator output will be shorted before all the flux has been delivered to the load. If the armature angle is greater than the stator angle, there will be a tail on the output pulse that will increase the current-doubling time.

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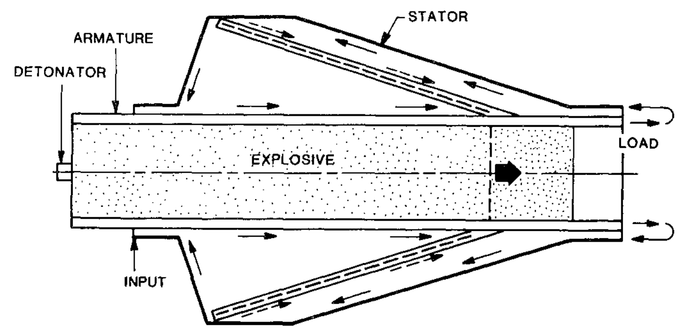

Fig. 1. Operation of the sweeping-wave coaxial generator. The dashed lines represent the positions of the armature and detonation front near the end of the run.

Description of the Coaxial Generator

A simplified cross-sectional view of the sweeping-wave coaxial generator is shown in Fig. 2. The explosive is PBX 9501, 76.5 cm long and 22.9 cm in diameter. The weight is about 58 kg. The armature is a fully annealed 6061 aluminum tube, 22.9 cm I.D. with a 11.4 mm wall. The stator is formed from OFHC copper. The maximum inner diameter is 62.9 cm. The half-angle of the input cone is 70^0; that of the output cone is 19^0. Although the inside dimensions of the stator were held to close tolerances, the wall thickness varied from 9.7 mm to 12.2 mm. Lead sheet (12.7 mm thick) was wrapped closely around the output cone and load to inhibit expansion under magnetic forces. The load was a coaxial inductor formed by an extension of the armature and an outer section of thick copper hard-soldered to the throat of the output cone.

The insulator at the input end was machined from glass-filled polyurethane plastic and used for the vacuum seal. The vacuum was provided by a turbo-molecular pump backed by a mechanical forepump. Vacuum quality for the shots was in the range 2-5 x 10^{-5} Torr. A P-80 plane-wave system was used to initiate the main charge.

The half-angle of the armature cone was measured to be 21.8^0 under no-load conditions. The angle of 19^0 for the stator cone was obtained from estimates of the effects of the magnetic pressure on the armature expansion under full load conditions.[2] The initial generator inductance was 70.5 nH; the load inductance was 12.5 nH, giving a no-loss current multiplication of 6.64.

A helical sweeping-wave booster generator[3] was used in series with the coaxial generator on the three full-power experiments. The booster gave an initial current of ~10 MA in the coaxial generator when used

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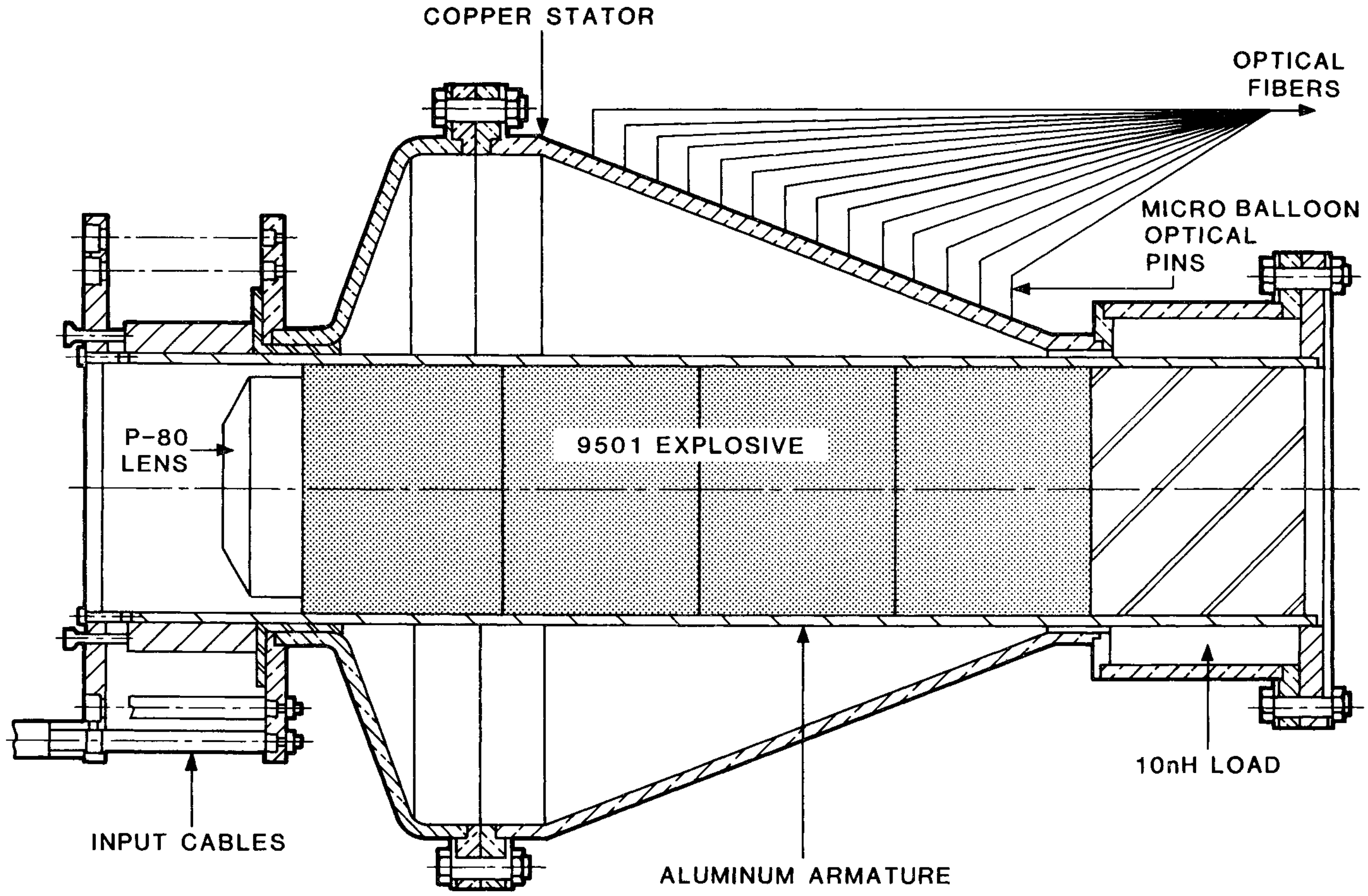

Fig. 2. Simplified drawing of the coaxial generator used in the tests.

with the available 900 kJ capacitor bank. The ultimate capability of the booster is 14 MA into the coaxial generator if the capacitor bank energy were to be doubled.

Diagnostics

The primary electrical diagnostics consisted of current pickups at the inputs to the two generators and in the load. We used both conventional Rogowsky loops and fiber-optic Faraday rotation sensors. The latter technique has been reported elsewhere in some detail.[4] The two types of current measurements agreed to within a few percent. The dI/dt records were obtained from the Rogowsky loops alone; however, numerical integration was employed to assure that they agreed with the passive integrators and the Faraday rotation sensors.

Arrays of optical-fiber pins were distributed along the outside of the stator output cone in order to measure the arrival time of the armature at the stator. This measurement gave a good estimate of the effects of high currents on the dynamics of the armature. Argon-filled glass or plastic spheres were used as sensors. When a strong pressure pulse goes through a sphere, the shock-heated argon emits a bright flash. The technique and its application to the coaxial generator has also been described elsewhere.[5,6]

Experimental Results

Four shots were fired in the test series. The first shot employed only the capacitor bank without the booster generator as the initial current source. The purpose was to test the diagnostic and timing setup and to provide comparison data from a low-power shot. The initial current was 2.1 MA; the peak current was 13.2 MA. Peak multiplication was 6.22 --- 94% of the no-loss estimate. The optical-fiber pins showed that the armature impacted the stator output cone first at the large diameter end. The contact point then swept toward the output end in good agreement with the no-load calculations.[6]

The last three shots were fired with the helical booster in series with the coaxial generator. In all cases, the initial current in the coaxial generator was 9.5 MA. This current was set by the capabilities of the available capacitor bank. The first full-power test gave poor electrical data owing to the collapse of the load under magnetic forces. A solid brass plug was placed in the armature under the load section for the last two shots. In both cases, a peak current of 50 MA was obtained corresponding to an energy of 15.6 MA. The current-doubling time was 12.5 μs. The current vs. time curve is shown in Fig. 3. For comparison, the low-power curve is shown suitably scaled with the input current in the later tests. At peak current, the loss is about 10% greater than that for the low-power shot. The optical pin records indicated essentially the same sweeping of the armature-stator contact that was observed for the low-power shot.[6] For completeness, the power and energy curves for the full-power shots are shown in Figs. 4 and 5 respectively.

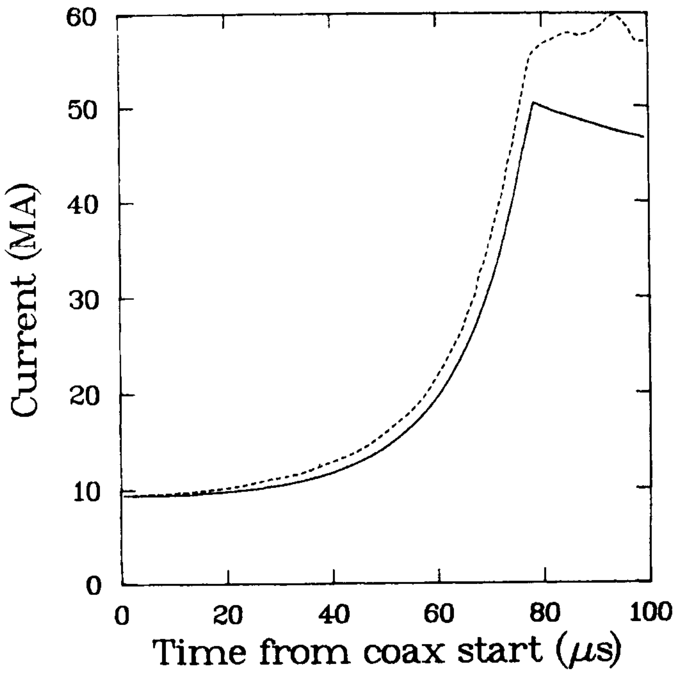

Fig. 3. Current vs. time curve for the coaxial generator. The solid line is the data from a high-power shot; the dashed line is the data from the low-power shot scaled to the same initial current.

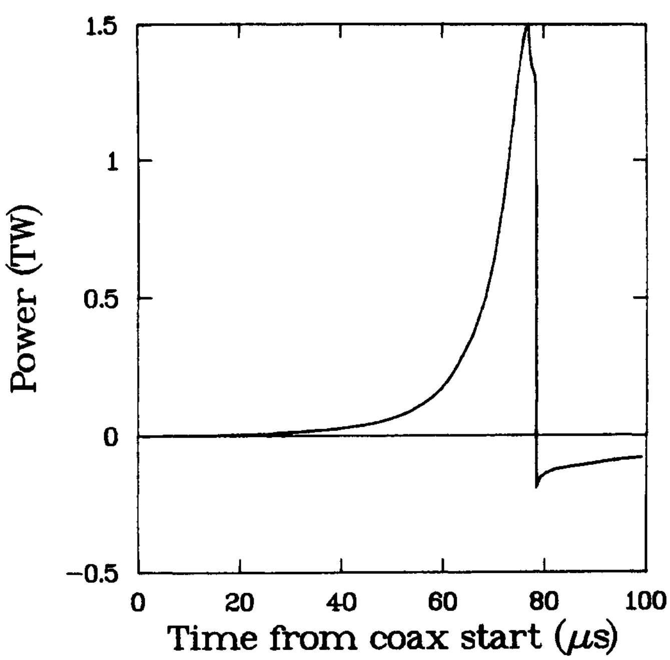

Fig. 4. Power delivered to the 12.5 nH load in the high-power shot. The curve is calculated from LI(dI/dt).

Conclusions

The test results show that the performance of the coaxial generator was little affected by the high currents up to the 15 MJ level. It is safe to say that, with a larger capacitor bank, we can reach 20 MJ with this system. Also, since the final current-doubling time is proportional to the load inductance for this generator, a 10 μs doubling time would be obtained for a 10 nH load.

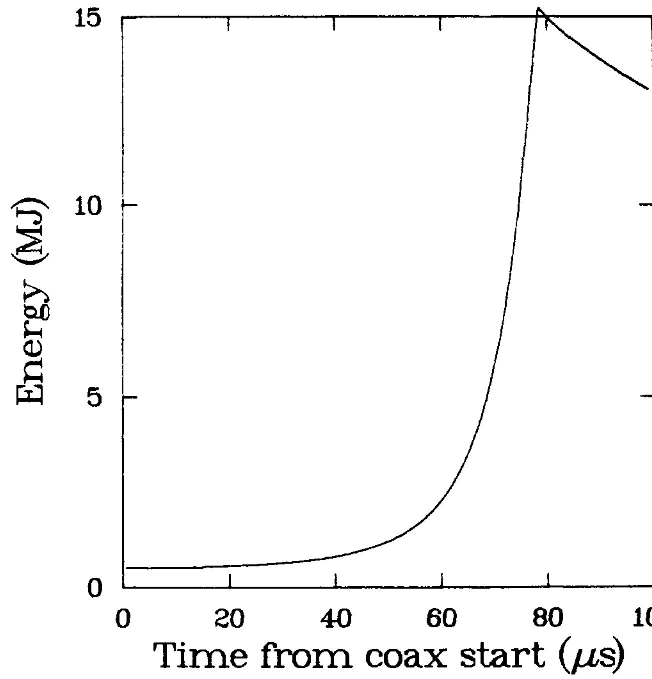

Fig. 5. Energy delivered to the 12.5 nH load in the high-power shot. The curve is calculated from $LI^2/2$.

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